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Review Paper

Advances in Biosynthesis of Nanoparticles: A Review

Rusul K. Ismail[1], Shahlaa M. Abd Al Hussan[2], Saif Khalel Jasim[2,3*]

[1] *College of Dentistry, University of Diyala, Ba'aqubah, Diyala, 32001, Iraq*
[2] *Ministry of Education. Diyala Education Directorate, Diyala, 36001, Iraq*
[3] *School of Physics, Universiti Sains Malaysia, Penang, 11800, Malaysia*
[*] **Corresponding author**: saifalaosy@gmail.com

Abstract
This paper provides a detailed review of nanoparticle biosynthesis, highlighting biological synthesis methods in comparison to physical and chemical approach. It addresses the shortcomings of existing techniques and explores potential advancements in this field. And, the applications of the nanoparticles prepared in a biological in the medical field, as well as studying its advantages and disadvantages, were highlighted. The paper review also provides a brief overview of nanoparticle applications, linking them to both the desired and achieved sizes through various synthesis methods.

Keywords
Biosynthesis, Green Synthesis, Advances, Application of Nanoparticles

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1. INTRODUCTION

Nanotechnology has begun to transcend laboratory boundaries and take over new applications that have the potential to transform our lives. When compared to big bulk materials, these nanoparticles' distinct chemical, optical, mechanical, and mechanical capabilities are caused by their larger surface area (Mazur, 2004; Ahmed et al., 2024b; Faraday, 1857). Mesopotamian artists created sparkling effects on pots by using nanoparticles. In his work, published in 1857, he examined the experimental relationships between light, gold (Au) and other metals. Faraday demonstrated the characteristics of nanoparticles (Jasim et al., 2021b; Raveendran et al., 2003). Nanoparticles' amazing qualities have made them important in a number of sectors throughout the last few years, including agriculture, health care, energy, and the environment (Ahmed et al., 2024a). One of two methods is used to prepare nanoparticles: (i) synthesizing nanoparticles, or (ii) turning nanomaterials into particles with nanostructures (Hussein et al., 2024; Roco, 2005). The silver nanoparticles are made by physical, chemical, and biological techniques (Jasim et al., 2024). The chemical and physical approaches are highly costly (Li et al., 1999). Biological methods of nanoparticles synthesis would help to remove harsh processing conditions by enabling the synthesis at physiological pH, temperature, pressure, and at the same time at lower cost. Numerous microorganisms have been discovered to be able to create composites of inorganic nanoparticles either extracellularly or intracellularly (Raveendran et al., 2003; Jasim et al., 2021a). Given all of this, this review presents a thorough analysis of the literature that is now available on the various biosynthetic techniques, their associated benefits and drawbacks, the many uses for silver, and gold nanoparticles, and upcoming developments in nanoparticle production and applications.

2. NANOPARTICLES SYNTHESIS METHODS

2.1 Bio Production of Nanoparticles

There are several methods for producing nanoparticles, including biological, chemical, and physical procedures. The chemical approach has the advantage of being able to swiftly produce large amounts of nanoparticles. This method involves the use of capping agents in order to stabilize the nanoparticle's size. Additionally, the chemicals and reagents that are frequently used to synthesize and stabilize nanoparticles are dangerous and generate byproducts that are detrimental to the environment. Interest in biological approaches that do not include the use of hazardous chemicals as byproducts is growing as a result of the demand for environmentally benign, nontoxic ways for the preparation of nanoparticles. Plants, fungi, actinomycetes, yeast, bacteria, and other natural sources can all be used to make metal nanoparticle (Tiwari et al., 2025; Sadeghi-Kiakhani et al., 2025). Both unicellular and multicellular organisms are capable of producing external and interior inorganic nanoparticle. Table 1 provides a summary of the biological synthesis of nanoparticles, and these bodies prepared in many applications can be used, including to reduce environmental pollution and in medical and industrial applications, as shown in Figure 1.

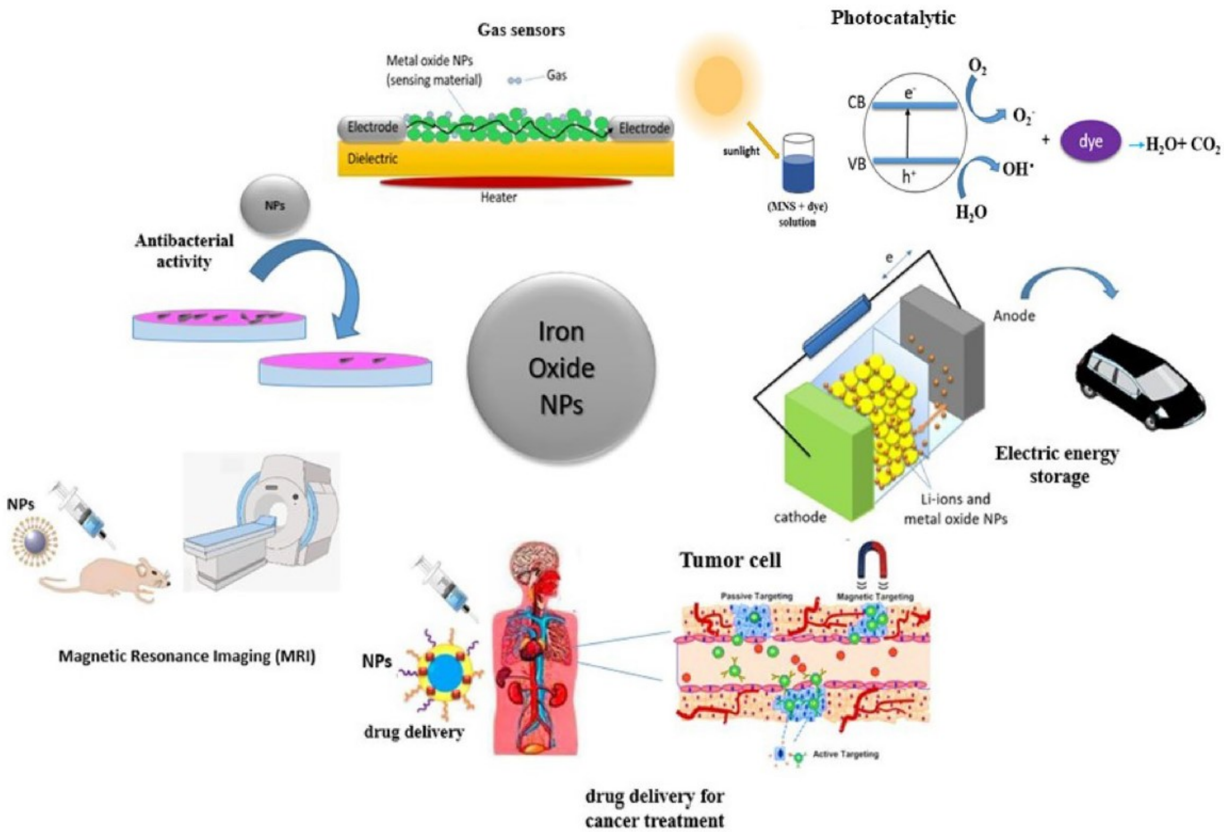

Figure 1. Shows the Nanoparticles Applications

2.2 Plant in Nanoparticles Synthesis

Singaravelu et al. (2007) reported synthesizing AuNP and AgNP using geranium extracts, proving that protocols using plant sources are free of hazardous compounds, making them a finer choice for the synthesis of nanoparticle, and the plants may conveniently supply natural capping agents. Additionally, plant extracts from *Aloe vera* were used to create silver nanoparticles and gold nanotriangles (Shiv Shankar et al., 2004). Broths made by boiling fresh plant leaves are used in the majority of papers on the production of Ag or Au nanoparticles. Nevertheless, Huang et al. (2007) employed a sun-dried extract of *Cinnamomum camphora* leaves, Bharde et al. (2006) to create silver and gold nanoparticles. Loveley et al. (1987) have reported a straightforward green synthesis method for producing well-defined silver nanowires. The process entails reducing silver nitrate with room-temperature broth made from sun-dried Cassia fistula leaves without the use of any additives. Table 1, lists of different plants and plant tissues, the nanoparticles made from them, their size and shape, and the references.

2.3 Bacteria in Nanoparticle Synthesis

Because of their rapid growth and relative simplicity of genetic modification, bacteria have been the subject of the most research when it comes to the creation of nanoparticles. Slawson and associates discovered that *Pseudomonas stutzeri* AG259, the silver producing bacteria isolated from the Ag mines, had collected Ag nanoparticles in the periplasmic space. The particles' sizes ranged from 35 to 46 nm (Shankar et al., 2003). Silver, gold, and alloy crystals with certain morphologies were created by exposing the lactobacillus strains found in milk to higher concentrations of nanoparticles (Chandran et al., 2006). Gold nanoparticles have also been produced using bacteria (Huang et al., 2007). The PH had a crucial role in regulating the site of the deposition and the shape of the bacteriogenic nanoparticles. Numerous applications, such as the direct electrochemistry of proteins, employed these nanoparticles (Lin et al., 2010). The industrial recovery of silver would be the most significant use of bacteria.

2.4 Yeast in Nanoparticle Synthesis

When exposed to dissolvable Ag during the log phase of development, most of the Ag forms elemental nanoparticles outside of cells, as demonstrated by Kowshik et al. in MKY3, a yeast species that can handle Ag. When exposed to dissolvable Ag during the log phase of development, the metallic nanoparticle are removed from the medium by differential sample thawing (Slawson et al., 1992).

2.5 Fungi in Nanoparticle Synthesis

Fungi are at the forefront of research on the biological creation of nanoparticles due to their bioaccumulation and tolerance

Table 1. Biosynthesis of Nanoparticles

Sources	Name of the Organisms	Localization	Types of Nanoparticle Produced	Size Range (nm)	References
Plant	*Azadirachta indica* (Neem) Extract	Extracellular	Ag, Au	100–50	(Shiv Shankar et al., 2004)
	Avena sativa (Oat)	Extracellular	Au	5–85	(Shiv Shankar et al., 2011)
	Geranium Leaves Plant	No	Ag	16–40	(Armendariz et al., 2004)
	Aloe vera	Extracellular	Au	5–85	(Chandran et al., 2006)
Fungi Sources	*Fusarium oxysporum*	Intracellular	Au	40–25	(Ahmad et al., 2003a)
	Verticillium sp.	Extracellular	Ag	12–25	(Mukherjee et al., 2001)
	Schizosaccharomyces pombe	Extracellular	Ag	25–5	(Bhainsa and D'Souza, 2006)
	Fusarium oxysporum	Extracellular	CdS	50–20	(Kowshik et al., 2003)
	Verticillium sp.	–	Magnetite	–	–
Yeast	Yeast-strain MKY3	Extracellular	Ag	2–5	(Bharde et al., 2006)
	Candida glabrata	Intracellular	CdS	200	(Kowshik et al., 2003)
	Schizosaccharomyces pombe	Intracellular	CdS	200	(Dameron et al., 1989)
Bacteria	*Pseudomonas stutzeri*	Intracellular	Ag	200	(Klaus et al., 1999)
	Lactobacillus strains	Intracellular	Ag, Au	No	(Nair and Pradeep, 2002)
	Escherichia coli	Intracellular	CdS	2–5	(Sweeney et al., 2004)
	Klebsiella pneumonia	Extracellular	Au	5–32	(Shahverdi et al., 2007)

(Konishi et al., 2004). The benefits of employing fungus in their fermentation process (e.g., a thin solid substrate approach) for scaling up. Extracellular enzymes are efficiently secreted by fungi, which makes large scale enzyme manufacturing simple. The economic viability and simplicity of biomass management of utilizing a fungal-mediated green technique for the preparation of metallic nanoparticle are two additional benefits. The primary disadvantage of creating nanoparticles in eukaryotic organisms is the inability to genetically modify the organism to overexpress the enzymes, which is comparatively more difficult in eukaryotes than in prokaryotes. Trichoderma asperellum, a nonpathogenic and significant agricultural fungus, was shown by Du et al. (2007) to produce highly stable nanocrystalline silver particles through "green synthesis".

2.6 Algae in Nanoparticle Synthesis

Although algae and yeast are similar in their ability to biosynthesize nanoparticles, only a small number of studies have employed algae as a bio manufactory for the production of nanoparticle (Konishi et al., 2004). The marine algae utilized to biosynthesize exceptionally steady extracellular AuNPs did so in a relatively short period of time when compared to earlier biosynthetic procedures (Sastry et al., 2003). Beginning with the equivalent metallic chloride containing salts, palladium and platinum nanoparticles have been studied (Mukherjee et al., 2008).

2.7 Actinomycetes in Nanoparticle Synthesis

Scientists are interested in the monodispersity of the intracellular or extracellularly generated silver and gold nanoparticles. However, it was significantly lower than that achieved using traditional procedures and was not particularly high. When exposed to Au and Ag irons, the majority of actinomycetes, particularly thermophilic actinomycetes like *Thermomonospora* sp., experienced an extracellular reduction in the metals (Singaravelu et al., 2007). To survive in such harsh environments, these microorganisms have evolved a variety of unique adaptations, such as a novel enzyme transduction mechanism, metabolic regulation, and membrane structure and function maintenance. Microorganisms known as actinomycetes can have key traits in common with bacteria and fungi (Ahmad et al., 2003b). The actinomycetes were initially referred to as "ray fungi" (*Strahlenpilze*), despite their strong kinship with mycobacterium and coryneforms. Secondary metabolites can be produced by these actinomycetes. Additionally, it was discovered that the nanoparticles were nontoxic to the cells, which kept proliferating even after they formed.

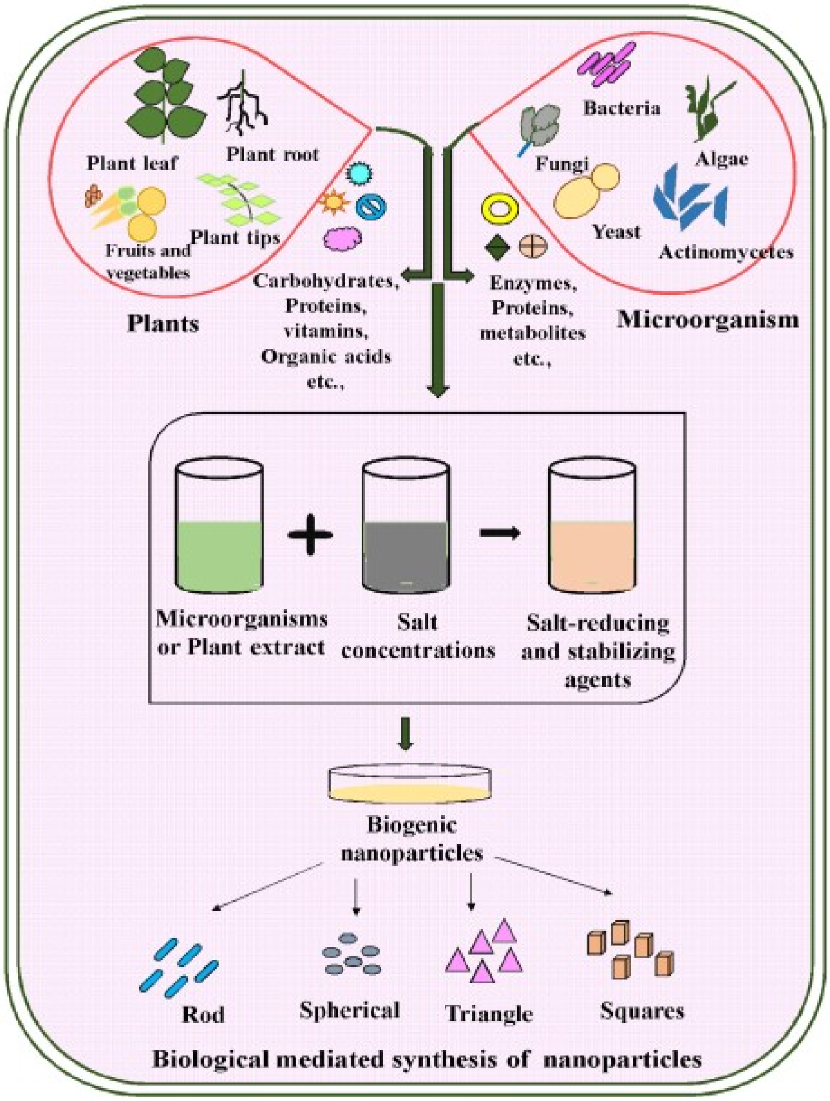

Figure 2. Pictorial Presentation of Biologically Mediated Synthesis of Nanoparticle (Gopalu et al., 2023)

2.8 Viruses in Nanoparticle Synthesis

Proteins, peptides, viruses, and enzymes are examples of biological particles that can now be produced as biological nanoparticles. Inorganic materials have been mineralized through the application of the cowpea mosaic and chlorotic mottle viruses (Okami et al., 1988). It has been demonstrated that the tobacco mosaic virus may effectively guide the mineralization of crystalline and sulfur containing nanowires. Furthermore, combinatorial screens have shown peptides that can initiate nanocrystal development, which are then visible on the surface of the M13 bacteriophage (Douglas and Young, 1993), as shown in Figure 2.

3. APPLICATIONS

Food storage, textile coating, antibacterial agents in the medical field, and various environmental applications have all made substantial use of AgNP. It's significant to remember that the proof of Ag toxicity is still unclear despite decades of use (Zhong et al., 2007). Silver nanoparticles' antibacterial qualities have made it possible for them to be used in a variety of applications, including water treatment, household appliances, and disinfection (Bosetti et al., 2002). Nanoparticles' chemical characteristics and catalytic activity are not the same, as shown in Figure 3.

3.1 Silver Dressing

The use of dressings is a crucial component of wound care (Slawson et al., 1992). Its toxicity to microorganisms and well-known antimicrobial properties make silver now utilized in a variety of formulations, such as surface coating agents and wound dressings (Leaper, 2006). In chronic wounds, nanocrystalline silver gels, lotions, and dressings effectively reduce bacterial infections.

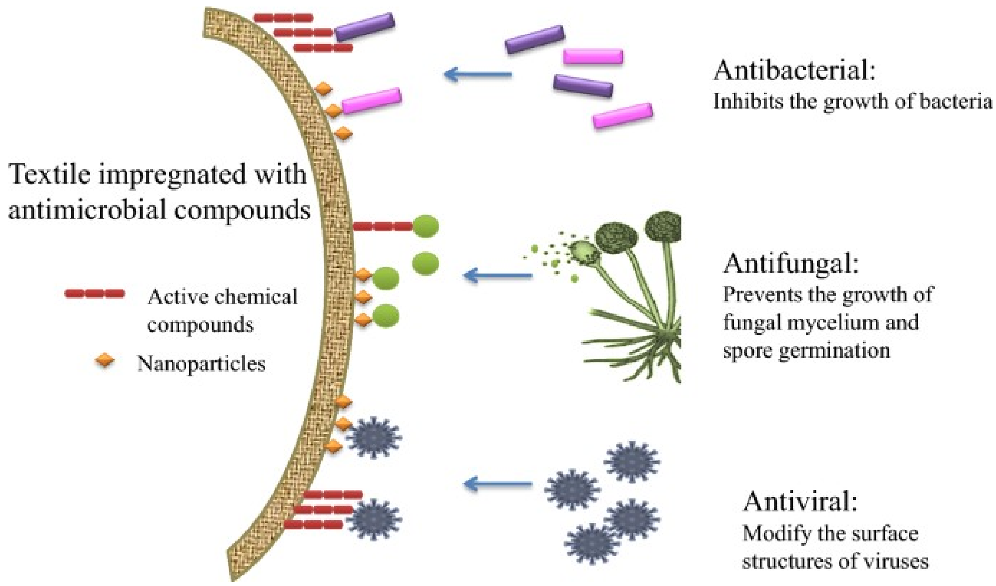

Figure 3. Types of Antimicrobial Textile (Duran et al., 2007)

3.2 Silver Toxicity

When there is a huge open wound and a lot of silver ions are used for dressing, the toxicity of the silver is seen as argyria. Silver allergy Du et al. (2007) is not commonly reported. It's important to remember that the proof of silver's toxicity is still unclear even after decades of use. Although there are many potential uses for nanotechnology in industries like electronics, engineering, and medicine, etc., little researches papers has been done on the potential negative impacts of nanoparticles. Therefore, a thorough investigation must be conducted before the release of nanomedicine related items onto the market (Duran et al., 2007), as shown in Figure 3.

3.3 Environmental Applications

To prevent environmental contamination, silver nanoparticles can be utilized to purify water. They can also be used to create environmentally friendly antimicrobial nanopaint. A variety of goods use inorganic composites as preservatives (Leaper, 2006). Water filtering is one application for silver nanoparticles (Kumar et al., 2008). AgNPs are antibacterial agents with a broad range of uses, including water treatment and cleaning equipment and household appliances. Water source contamination has become a worrying problem in recent years. Wastewater treatment is one method of addressing this pressing problem. However, because of time constraints and the existence of harmful chemicals, conventional procedures are unable to fully eliminate the pollutants in the water (Ahmed et al., 2021). When it comes to cleaning up contaminated water, nanoparticles can be very helpful. Wastewater is effectively treated using a variety of nanoparticle (Das et al., 2018). For the degradation of dyes, green synthesis of Fe/Pd and Fe bimetallic NPs has been employed. Green tea extracts were utilized to reduce the green dye of malachite, grape leaf extract was used to remove the orange II dye, and extracts from eucalyptus globules were used to reduce the hexavalent chromium. Additionally, eucalyptus leaf-derived FeNp demonstrated promise for treating swine effluent. These particles effectively removed total phosphates, ammonia nitrogen, and chemical oxygen requirement (Devatha et al., 2016). discovered that CuO-NPs isolated from the *Madhuca longifolia* plant have outstanding photocatalytic properties for breaking down the color methylene blue. They therefore offer a lot of potential for wastewater treatment as photocatalysts. Another work created titanium dioxide (TiO_2) nanoparticles using extracts from *Jatropha curcas* L. (Das et al., 2018). According to the study, (TiO_2) NPs are useful for wastewater photocatalytic treatment. The nanoparticle extracted 76.48% of the chromium (Cr) and 82.26% of the chemical oxygen demand (COD) from the contaminated water (Goutam et al., 2018). We may therefore draw the conclusion that nanoparticles have a great deal of promise for application as an alternative wastewater treatment technique that is safe for the environment.

3.4 Cytotoxicity, Autophagy, and Mutagenicity

Green manufactured nanoparticles have gained notoriety for generating cytotoxic chemicals that combat various cancer kinds. However, the safety of employing these materials is still a worry because, if employed as a treatment, these potent substances have the ability to destroy both healthy and cancerous cells. Scientists are working to develop an anticancer medication that is stable, biocompatible, has a broad therapeutic index, especially to the target site, is biodegradable, has few adverse effects, is affordable, and is easy to manufacture. The size and shape of the particle are significant factors that significantly affect cytotoxicity. The pharmacodynamics and pharmacokinetics of nanoparticles are also influenced by surface charges, surface area, attached functional groups, surface characteristics, solubility, and agglomeration/aggregation state. The review claims that compared to Au, Ag and plant mediated nanoparticle exhibit greater cytotoxic activity. The size and form of the particles mostly determine the cytotoxicity (Hanan et al., 2018). According to a review, average-sized, smaller metallic nanoparticles have a higher probability of being cytotoxic to cell lines. Additionally, it has been demonstrated that MNPs may be less cytotoxic in normal cell lines, but this does not mean that they are harmless. To get a firm judgment, more research on this subject is required (Barabadi et al., 2018). According to yet another study, ZnO nanoparticles are notably less harmful to healthy cells. Cytotoxicity depends on the drug used and the type of cell. According to the study, ZnO-NPs exhibit potent cytotoxicity against cancer cells (Selim et al., 2020). It demonstrates that the nanomaterials are more biocompatible with healthy cells and more harmful to malignant cells. Under certain conditions, a cellular mechanism called autophagy enables the cell to break down its cytoplasmic constituents, such as organelles and unfolded proteins (Abul et al., 2016). Human cells undergo autophagy when exposed to NPs. To do this, oxidative stress and reactive oxygen species (ROS) are employed (Bai et al., 2017). The cellular responses that autophagic NPs trigger are intricate. Pathogenic responses in cells are often triggered by nanoparticles. The autophagic reaction is regulated by the nanoparticles' size and concentration. When NPs build up in autophagosomes, they can disrupt the autophagy flow by reducing or impeding lysosomal stability and enzyme activity, which can interfere with the cytoskeleton's capacity to transport vesicles. This can increase the risk of cancer and other illnesses by blocking autophagy. Certain nanoparticles, like manganese NPs and TiO_2 NPs, have the ability to trigger an autophagic response that could lead to cell death (Mohammadinejad et al., 2019). According to another study on AgNPs, cells treated with silver nanoparticles that have been exposed to high levels of ROS may exhibit impaired autophagic function. Cells may experience oxidative stress as a result of the accumulation of damaged organelles. Numerous sources of nanoparticles have been shown to stimulate the production of autophagosomes in treated cells. High intracellular ROS concentrations in cancer cells lead to increased oxidative stress and potential cell death. ROS preferentially targets cancer cells over healthy or normal cells. This has been highlighted by the potential use of autophagy to induce cell death as a therapy for cancer and other neurological diseases (Abul et al., 2016). It is possible for mutagenic chemicals to interact chemically with DNA and harm it. Since people frequently come into contact with these substances, it is a matter of worry. One of the contributing factors to cancer and other diseases is DNA damage. The creation of anti-mutagenic substances is one way to stop this. AgNPs have been found to exhibit potent anti-mutagenic action against the S. *Typhimurium* strains TA100 and TA98. At greater concentrations, it exhibited considerable action. This study is thought to be the first to examine silver nanoparticles' anti-mutagenic properties (Sarac et al., 2017). Many studies have been carried out to evaluate the mutagenicity of nanoparticles. A study on ZnO and AgNPs found that they do not show mutagenic potential (Mumtaz and Munir, 2019). Another study also found Mentha arvensis synthesized AgNP to be non-mutagenic in tester strains of Salmonella typhimurium (TA1538, TA1535, TA100, and TA98). This concentration is up to 5 mg per plate. AgNPs isolated from *Daphne mucronata* did not cause mutations in the TA98 and TA100 strains of S. *Typhimurium* (Dey et al., 2019).

4. FUTURE PROSPECTS

Due to their distinct physical and chemical properties relative to their bulk size constituents, nanoparticles are frequently utilized to enhance a variety of catalytic reactions. Industrial production of nanoparticles is necessary due to their numerous applications. As previously mentioned, there are numerous drawbacks to the physical and chemical approaches of creating nanoparticles. Given its environmentally favorable approach, biological synthesis would be the method of choice (Gong et al., 2007; Gupta and Silver, 1998). Nevertheless, very little research has been published on the variables influencing or driving metal nanoparticle biogenesis. The use of microorganisms in the manufacture of nanoparticle has progressed during the last few decades. It is well known that, in contrast to physical and chemical technique's, the creation of nanoparticle utilizing microbes is a somewhat sluggish process. Microorganism based synthesis is still done in lab settings. Examining the potential used of microbes in the production of nanoparticle should be a priority (Jain and Pradeep, 2005). Nanoparticles have already been used for a number of medical purposes, including treating preclinical phases, healing wounds, and preventing infections. Exciting new biological characteristics of NS have been discovered recently, and these could be developed into novel pharmacological and therapeutic interventions (Oberdorster et al., 2005). This technology has not yet reached its full potential. Numerous studies have been conducted on the antiviral, antifungal, and antibacterial qualities of silver ions, compounds, and nanoparticles (Sabri et al., 2024). In trace amounts, silver has also been shown to be non-toxic to humans. Since silver targets a wide variety of germs, it is less likely that microorganisms may become resistant to it than to antibiotics (Kenyon and Solomon, 2025; Mahmood et al., 2025). To comprehend the toxicity, experiments are required. The precise mechanism by which AgNPs interact with bacterial cells, Some of the difficulties that need to be addressed include how the surface area of the nanoparticles affects their killing activity and how clinical research and animal models can be utilized to better understand the antibacterial efficiency of silver dressings, whether any silver dressings are toxic, etc. (Pletts and Burrell, 2025).

5. ADVANTAGES

The benefits of employing nanoparticles for drug delivery stem from their two primary characteristics. First, due to their small size, nanoparticles can enter narrower capillaries and be absorbed by cells, enabling effective drug accumulation at the intended locations. Second, the creation of nanoparticles using biodegradable materials allows for extended drug release within the target region over days or even weeks (Shinde, 2012). However, nanoparticle are crucial for more than just medications. Numerous electronic devices, processes, and applications have the potential to be completely transformed by nanotechnology. When it comes to electronic devices, the ongoing advancement of nanotechnology benefits a wide range of industries, including quantum computers, OLED, plasma displays, nano diodes, and nano transistors. The energy industry can potentially profit from nanotechnology. This method may allow for the reduction of size without sacrificing efficiency in goods such as solar cells, fuel cells, and batteries. Manufacturing is another sector that could gain from nanotechnology, which needs materials like aerogels, nanotubes, nanoparticles, and other similar products to create their products. These materials are frequently stronger, lighter, and more resilient than those made without the use of nanotechnology (Nanogloss, 2015). Beyond their manufacturing and drug delivery methods, nanoparticles provide a few additional benefits. Drugs use nanoparticles to target particular locations since they are relatively easy to create. Nanoparticles can enter tiny capillaries and be absorbed by cells due to their small size, allowing medications to accumulate effectively in the right places in the body. Nanoparticles offer good size control and drug encapsulation protection when employed in drug delivery. The drug's clearance time is longer when it is kept at the active site. Nanoparticles improved both the bioavailability and therapeutic efficacy. They improved medication stability by lowering fed/fasted variability and maintaining pharmacological dosage forms that, in non-nanoparticulate dosage formulations, have unacceptably low bioavailability or are unstable. When using nanoparticles to transport drugs, the carrier is not biotoxic. Nanoparticles merely avoid organic solvents and do not exhibit any issues during large-scale manufacture or sterilization (Shinde, 2012; Yadav, 2013).

6. DISADVANTAGES

When discussing the benefits and drawbacks of nanotechnology, we must also highlight what may be considered the technology's drawbacks. Included in the list of disadvantages of this science and its development is the possible loss of jobs in the traditional farming and manufacturing industry. It is now possible to create more potent and deadly atomic weapons and make them more widely available. Nanotechnology can also make these more accessible. Nanotechnology has also raised health risks. Because of their small size, nanoparticles can cause inhalation problems and a number of deadly diseases. Inhaling nanoparticle-contaminated air for just 60 seconds can easily harm the lungs. Nanotechnology can be very expensive to develop and is already very expensive. Furthermore, it is quite difficult to produce, which perhaps explains why goods based on nanotechnology are more expensive (Nanogloss, 2015). Although nanotechnology has improved living standards, it has also led to a rise in pollutants, including air and water contamination. Nano pollution is the term used to describe the contamination brought on by nanotechnology. Pollution of this type is extremely harmful to living things. There is virtually little research on the drawbacks of nanoparticles. Thus, there are only a few more of them based on drug delivery. When creating drug delivery nanoparticles, polyvinyl alcohol is frequently employed as a detergent, which raises questions regarding toxicity. Because nanoparticles have limited targeting capabilities, therapy cannot be discontinued. Alveolar inflammation and cytotoxicity are demonstrated by drug delivery using nanoparticles. The disruption of autonomic balance caused by nanoparticles directly affects vascular and cardiac function. Particle growth, erratic gelation tendencies, unanticipated polymeric transmission dynamics, and sometimes explosive discharge are all features of nanoparticles (Shinde, 2012; Yadav, 2013).

7. CONCLUSIONS

In this article, we studied the previous literature on nanoparticle biosynthesis and its applications. Living things have enormous potential for producing nanoparticles and nanodevices with a variety of uses. It is possible to produce nanoparticles or nanodevices with the appropriate size and form by utilizing organisms in the reaction mixture, ranging from basic bacteria to extremely complex eukaryotes. Although nanobiotechnology is still in its early stages, some of the examples used in this article to illustrate this technology and how it is used will draw people's attention to its uses. Among these studies, a few have shown that different kinds of reductases of these organisms might be involved in the mechanism of nanoparticle production and attribute to them various shapes and size. However, much more research is required to determine the precise mechanism of producing nanoparticles utilizing living creatures.

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